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Michael J. Duncan, Elizabeth Bryant, Matthew Hill, Michael J. Price, Samuel W. Oxford, Emma L. J. Eyre,

Centre for Applied Biological and Exercise Sciences, Coventry University, Coventry, UK

Address for correspondence: Michael J. Duncan, Centre for Applied Biological and Exercise Sciences, Coventry University, James Starley Building, Priory Street, Coventry, UK, CV 5HB. E-mail: michael.duncan@coventry.ac.uk

Running Head: Postural sway in children

This study examined postural sway in children in eyes open (EO) and eyes closed (EC) conditions, controlling for Body Mass Index (BMI) and physical activity (PA). Sixty two children (aged 8-11years) underwent sway assessment using computerised posturography from which 95% ellipse sway area, anterior/posterior (AP) sway, medial/lateral (ML) sway displacement and sway velocity were assessed. Six trials were performed alternatively in EO and EC. BMI (kg/m^2) was determined from height and mass. PA was determined using sealed pedometry. AP amplitude (P= .038), ML amplitude (P= .001), 95% ellipse (P= .0001) and sway velocity (P= .012) were higher in EC compared to EO conditions. BMI and PA were not significant as covariates. None of the sway variables were significantly related to PA. However, sway velocity during EO (P= .0001) and EC (P= .0001) was significantly related to BMI. These results indicate that sway is poorer when vision is removed, that BMI influences sway velocity but pedometer assessed PA was not associated with postural sway.

Keywords: Sway; Obesity; Physical Activity; Postural Control

INTRODUCTION

Adequate postural stability is crucial for general motor development and for performance of activities of daily life (Westcott, Lowes, & Richardson, 1997). Due to the complexity of context-dependent multisensory reweighting, fully mature postural balance responses tend to occur later in childhood and into adolescence (Westcott, et al., 1997). Shumway-Cook and Woolacott (1985) previously reported data on balance development in children using The Sensory Organisation Test, that suggested mature postural control is developed in the age range 7-10 years. These data have since served as the standard timeline of postural development for educators and clinicians. The Sensory Organisation Test is a form of posturography which is designed to assess quantitatively an individual's ability to use visual, proprioceptive and vestibular cues to maintain postural stability in stance with mature postural control referring to the ability to maintain balance in quiet stance when sensory systems (vision, proprioception) are restricted or removed. Typically, when vision is removed (via closing eyes) postural stability is reduced and sway (e.g., sway velocity, sway path) variables amplified (Riach, & Starkes, 1993). The use of visual information is considered as the most important source of feedback for postural regulation and improves during childhood (Riach, & Starkes, 1994). Mature postural control develops as children progress from a ballistic strategy (open-loop control) with large and rapid corrections in sway to an integrated open-loop and closed loop of postural control resulting in shorted and more frequent excursions of COP with ability to better maintain stance when sensory conditions are diminished or removed (Riach, & Starkes, 1994).

Subsequent work by Rival, Ceyte & Olivier, (2005) suggested that short term (i.e. 5 seconds duration) postural control matures between the ages of 6 – 10 years with the underlying processes for maintaining postural stability reaching maturity at the age of 6 years. Conversely, Peterson, Christou, & Rosengren (2006) reported postural control in groups of 7-8 and 11-12 year old children. Mature postural control was not observed in the 7-8 year old group but was present in the 11-12 year old group. Similarly, mature postural control has been suggested not to become properly developed until the age of 15 years (Hirabayashi and Iwasaki, 1995). There is therefore debate regarding the age at which children's postural sway matures. The discrepancy in findings may be due to a number of factors including the use of different techniques to assess postural sway and, in the case of Rival et al. (2005), use of a very short time period (5 seconds) to collect quiet stance sway data. Rival et al. (2005) subsequently suggested a need for future research to assess sway in quiet stance of a duration longer than 10 seconds.

One factor which may impact on postural balance control is weight status. Studies have highlighted non-optimal motor development in overweight and obese children and that overweight and obesity constrains balance compared to normal weight children (D'Hondt, Deforche, De Bourdeaudhuij, & Lenoir, 2008). However the understanding of the impact of excess body mass on children's postural balance function is limited and not fully understood (D'Hondt, et al., 2008; D'Hondt, Deforche, De Bourdeaudhuij, Gentier, Tanghe, Shultz, & Lenoir, 2011). Thus it is unclear whether additional mass associated with obesity results in reduced postural stability in adults, children or both (Wearing, et al., 2006). Deforche, et al. (2009) reported poorer performance in overweight prepubertal boys when performing several static and dynamic balance tasks related to activities of daily living compared to normal weight prepubertal boys. This included slower speed when walking on a line, slower weight transfer and rising index in the sit to stand test and poorer one-legged static balance for overweight versus normal weight boys. Data from the Movement Assessment Battery for Children has also suggested that approximately 20% of the variance in balance sub-scores on this battery could be explained by children's body mass index (D'Hondt, et al., 2008), highlighting the importance of weight status in balance. Interestingly, Petersen, et al (2006) also conducted multiple regression analysis to examine the contribution of height, mass and BMI together along with gender and age on balance in their study. Like D'Hondt, et al., (2008) they reported, that physical characteristics explained 20% of the variance in scores on the Sensory Organization Test. Although it is not clear from their study why height, mass and BMI were entered into the regression model at the same time when BMI is created from height and mass. It is possible that such a process has the effect of inflating the associations reported by Petersen, et al (2006). Collectively, the evidence on the impact of weight status on postural balance suggests that excess mass likely results in poorer balance performance but research to date is far from definite, especially in pediatric populations. There is thus a need to provide additional evidence as to the effect of weight status on postural balance in children.

To date, few studies have applied computerised posturography in the assessment of postural stability in children, particularly with respect to weight status. Computerised posturography provides an objective means by which to quantify the central nervous system's adaptive mechanisms in the control of posture. A full review of this technique is beyond the scope of this paper but authors are referred to Pinsault and Vuillerme (2009) for an overview. McGraw, McClenaghan, Williams, Dickerson, & Ward (2000) reported decreased postural stability (increased sway areas and greater variability in sway amplitude), particularly in the medial-lateral direction, in obese compared to non-obese prepubertal boys during quite stance. Conversely, Bernard, Geraci, Hue, Amato, Seynnes, & Lantieri, (2003) and D'Hondt, et al. (2011) both reported no significant differences in postural control between normal and overweight children. Thus results are again equivocal.

One further issue, related to the examination of associations between weight status and postural control in children is that studies have not considered the potentially confounding effects of physical activity (Wearing, Hennig, Byrne, Steele, and Hills, 2006). Physical activity status has been shown to have a profound influence on balance performance in adults (Bulbulian, and Hargan, 2000) but few studies to date have actually considered habitual physical activity in any analysis of postural control in either children or adults. There is evidence that trained adult sports performers do not differ in postural control irrespective of sport performed (i.e. ballet dancers vs. track and field athletes) (Schmit, Regis, & Riley, 2005) but it is not clear whether individuals with a high level of habitual physical exhibit better or worse postural control than those with lower levels of physical activity. As there is an association between physical activity and obesity, it is also important to investigate whether habitual physical activity influences postural control in children, particularly in the age range between 7-11 years of age due to the reported maturation of postural control during this time (Petersen, et al., 2006). Thus, the present study was exploratory and sought to examine differences in postural sway in standing balance as a consequence of conventional altered sensory conditions (eyes open vs. eyes closed) in a sample of 8-11 year old British children whilst controlling for Body Mass Index (BMI) and habitual physical activity (PA). The age range in this sample are also purported to be at a point where postural stability can be maintained (Rival et al., 2005) but may still be maturing (Petersen, et al., 2006). We hypothesised that mediolateral and anteroposterior centre of pressure area would be greater, centre of pressure velocity, faster and centre of pressure path length longer in EC compared to EO conditions. We also hypothesised that higher BMI would be associated with increased mediolateral and anteroposterior centre of pressure area, slower centre of pressure velocity and longer path length whereas higher habitual PA would be associated with reduced mediolateral and anteroposterior centre of pressure area, faster centre of pressure velocity and smaller sway path length.

METHODS

Participants

Following institutional ethics approval, Sixty six primary school children (30 boys and 36 girls, 86% Caucasian) volunteered and returned signed parental informed consent forms to participate in the study. Children were aged 8-11years (mean age ± SD = 10.1 ± 0.8 years). Participants were included if they were 'apparently healthy' children aged 8 to 11 years. Exclusion criteria included; the use of a mobility aid or prophylactic device (e.g., knee brace), if they had a musculoskeletal impairment or injury or head injury (< 6 weeks) which was likely to affect their motor performance or diagnosed with any form of developmental disorder likely to influence motor performance (i.e., developmental coordination disorder, dyspraxia, dyslexia, Asperger's syndrome and autism). Four children (all boys) did not provide complete data for all variables of interest and were therefore removed from the final data set used for analysis resulting in a final sample of 62 children (26 boys and 36 girls) being included in the final data set.

Procedures

Anthropometry

Body mass (kg) and height (m) were measured to the nearest 0.5kg and 0.5cm respectively, using a stadiometer and weighing scales (Seca Instruments, Germany, Ltd) respectively. Children were assessed in bare feet and wearing shorts and t-shirt. Mean±SD of height (m) and body mass (kg) were 1.36 ± 1.7m and 35.5 ± 13.0 kg respectively. From this, body mass index (BMI) was then determined as kg/m^2 (Mean±SD = 17.8 ±4.6 kg/m^2). Based on IOTF criteria (Cole, Belizzi, Flegal, & Dietz, 2000) 83% of participants were classified as normal weight.

Physical Activity Assessment

Physical activity (PA) was assessed using a sealed, piezo-electric pedometer (New Lifestyles, NL2000, Montana, USA) worn over four days (2 X weekdays and 2 X weekend days) in accordance with recommendations for the assessment of physical activity in children and using protocols previously described (Duncan, Schofield, Duncan, & Hinckson, 2007). Furthermore, four days of monitoring is a sufficient length of time to determine habitual physical activity levels in children (Trost, Pate, Freedson, Sallis, & Taylor, 2000). Prior to the monitoring period, children were familiarized with the pedometers and were briefed as to the nature of their involvement in the study. On the first day of monitoring, the children were instructed on pedometer attachment (at the waist), its removal (only during showering/bathing, swimming or sleeping) and re-attachment before going to school each morning. The instructions were provided in language that was easily understandable and children were informed of any potential discomfort in wearing the pedometer. The children were requested to wear the pedometer from the time of waking up in the morning to going to bed at night (other than for swimming and bathing). They were also asked not to tamper with the pedometer and to go about their normal activities during the monitoring period. Across the period of measurement, the children were asked to complete a brief survey to verify that the pedometers were worn for the entire time of the study. Only children who provided 4 days monitoring data were included in the study and wear time was ascertained using the survey data. Once returned data was downloaded from the pedometer memory with average steps/day used as a measure of physical activity. Across the measurement period, the children completed a brief survey to verify that the pedometers were worn for the entire time of the study. Mean ± SD of average steps/day was 14386 ± 4272 with 63% of participants meeting children's steps/day guidelines for health (Tudor-Locke, et al., 2004).

Assessment of Postural Sway

Posturographic ground reaction forces were examined by means of a portable force platform (AMTI, AccuGait, Watertown, MA) at a sampling frequency of 100 Hz and subsequently analysed using the accompanying analysis software package (AMTI, BioAnalysis, Version 2.2, Watertown, MA) and following recommended guidelines for sway assessment (Pinsault and Vuillerme, 2009). To examine postural sway during upright stance, participants stood barefoot on the square platform (0.5 x 0.5 m) for 30 s with their eyes open (EO) or eyes closed (EC). To ensure continuity between trials, foot position was standardised using foot templates at a distance of 3 cm between the medial extremities of the posterior side of the calcaneus. Bipedal stance was selected in order to compare data with previous studies (Verbecque, da Costa, Meyns, Desloovere, Vereeck, & Hallemans, 2016). During each trial the arms were left to hang freely by their sides and participants were asked to stand as still as possible (Verbecque, *et al.* 2016). Each condition was explained in advance to each child. The trial was stopped in the child did not understand or follow the instructions. All participants were required to perform two EO and two EC familiarisation trials prior to measurements in an attempt to habituate individuals to standing. Each participant then performed trials alternatively with EO and EC for a total of six trials. There was no evidence of a learning effect in the three trials used for analysis in both the EO and EC conditions. An average of the three trials for each visual condition was used in subsequent analyses, similar to the procedure used by Hill, Oxford, Duncan, & Price (2015). Each trial was separated by a 15 s break allowing participants to step off the plate and relax. During the EO condition, participants were asked to focus on a 15 cm diameter black circle placed on a plain wall ~1.5 m in front of them at eye level. On the basis of vertical ground reaction forces recorded from the force platform, the system calculated the *x* (mediolateral, ML) and *y* (anteroposterior, AP) co-ordinates of the centre of pressure (COP) and the following variables were subsequently computed; (1) COP area with a 95% confidence ellipse (cm^2); (2) mean velocity of the COP movement ($cm \cdot s^{-1}$); (3) COP path length (cm); (4) excursion of the COP in the AP direction (cm); excursion of the COP in the ML direction (cm). We did not take into account typical stance or participant's height to determine the base of support. While the authors acknowledge that a self-selected comfortable foot position typically elicits a smaller amounts of postural sway compared to standardised approaches we selected a standardised position to ensure continuity both between and within participants, which is consistent with previous work in children (e.g., Verbecque, *et al.* 2016).

Statistical Analysis

Relationships between postural sway variables, BMI and PA were analysed using Pearson's product moment correlations. To examine differences in 95% confidence ellipse sway area, anterior/posterior (AP) sway, medial/lateral (ML) sway displacement and average sway velocity a series of mixed within-between subjects repeated measures analysis of covariance (ANCOVA) controlling for BMI and average daily steps were undertaken. In each case visual condition (eyes open vs eyes closed) was used as the within-subjects factor and gender was used as the between-subjects factor. Each of the sway variables was used as the dependant variable in turn. Where any significant differences were detected, Bonferroni post-hoc multiple comparisons were used to detect where these differences lay. Statistical significance was set a priori as P = .05, partial η^2 was used as a measure of effect size and SPSS Version 20 was used for all analysis.

RESULTS

None of the postural sway variables were significantly related to PA (all P>.05; Table 1). Mean sway velocity during EO (r = -.61, P = .01, See Figure 1) and EC (r= -.61, P = .01, See Figure 2) was significantly related to BMI (Table 1). Results from ANCOVA analysis indicated significant differences in AP sway amplitude ($F_{1, 58}$ = 4.49, P = .038, partial η^2 =.072), ML sway amplitude ($F_{1, 58}$ = 56.79, P = .001, partial η^2 =.483), 95% ellipse sway areas ($F_{1, 58}$ = 30.95, P = .0001, partial η^2 =.494) and average sway velocity ($F_{1, 58}$ = 6.78, P = .012, partial η^2 =.087), with values being greater in EC compared to EO trials. BMI and PA were not significant as covariates and there were no significant differences between gender groups in any of the analysis (all P>.05). Mean ± SE of sway parameters in EO and EC conditions are presented in Table 2.

DISCUSSION

The present study examined differences in postural sway as a consequence of altered sensory conditions (eyes open vs. eyes closed) in a sample of children whilst controlling for Body Mass Index (BMI) and habitual physical activity (PA). Although a number of studies have assessed balance in children using standardized field tests (Goulding, Jones, Taylor, Piggot, & Taylor, 2003; Deforche et al., 2009), far fewer studies have used computerised posturography to assess postural sway in pediatric populations. As a consequence the results of this study extend prior work which has used this method in children (D'hondt, et al., 2008, D'hondt, et al., 2011, Verbecque, et al., 2016, Peterson, et al., 2006). The results of the present study suggest that AP and ML sway displacement, 95% ellipse and sway velocity are increased in conditions where visual feedback is removed. This is not surprising and visual sensory input is one of the primary contributors to the maintenance of upright posture (Petersen, et al., 2006) and change of visual sensory input results in changes in postural stability (Horak, and Macpherson, 1996) in adults. These results are also congruent with prior work published by D'Hondt et al (2011) where removal of vision resulted in greater amounts of postural sway in 7-12 year old children. This study also suggests that greater sway velocity is associated with lower BMI. Greater BMI may result in slower shifts in the COP, due to motor latencies as a result of increased inertia, resulting in lower sway velocity. These results support prior assertions by D'Hondt, et al. (2011) that vision plays an important role in controlling children's postural stability but are also contrary to research published by McGraw et al (2000) who suggested obese boys were more reliant on vision to maintain postural control compared to non-obese boys.

The focus of the present study was on examining the differences in postural sway variables in quiet stance as a consequence of altered sensory conditions and controlling for BMI and PA, particularly as the latter covariate has been purported to influence postural sway but no study to date has empirically examined if this is the case in children. Although some studies had previously examined how BMI influenced sway in quiet stance, none had accounted for PA, a known influence on children's weight status. Despite the fact that PA was not significantly associated with postural sway in the children in the present study, it is important to highlight that this is the case. Without trying overstate the reach of the data presented here, without empirically examining if and how PA might influence postural sway variables in children, anecdotal assumptions that habitual PA will positively enhance postural sway in children, based on data using adult participants (e.g., Wearing, et al., 2006; Bulbulian, and Hargan, 2000) would likely persist. The fact that the current study has examined postural sway in children accounting for both BMI and objectively assessed PA should be considered novel irrespective of whether there were significant associations between sway variables and BMI or PA. On reflection a more rigorous sway assessment protocol might be useful in providing a more nuanced overview of how BMI and PA might influence postural sway under different sensory conditions. Although the sway protocol employed in the present study was relatively short in duration, when combined with the demands of familiarisation, assessment of

BMI and PA assessment, the overall burden on each child participant and associated time commitment was not minimal. Hence why, in the present study, the decision to only assess sway in quiet stance and EO and EC conditions was made. Other, more dynamic measures of balance or more challenging balance conditions may be needed to better understand how BMI and PA might influence postural sway in future studies. Likewise, use of more challenging sensory conditions, such as standing on one leg, might elicit a different association between BMI and sway parameters than documented in the present study.

Postural sway may not have been fully mature in the sample of children assessed in the current study and as suggested by prior authors (Hirabayashi, and Iwasaki, 1995), making the fidelity of any association between PA and postural sway more difficult to detect. This lack of 'maturity' has been characterised by greater variability in sway parameters with larger and more rapid regulation of body mass to maintain posture in quiet stance in children (Rival, et al., 2005). This can make establishing a linear improvement in postural sway with age more difficult in children (Rival et al., 2005). Likewise, although PA in children is largely ambulatory in nature (Welk, 2005), it also tends to be more multifaceted and comprises more a greater regularity of changes in movement. Using accelerometry to assess PA might therefore offer a method to capture the intensity of PA, which pedometers cannot. This could then be employed to examine whether any association between postural sway and PA in children is more related to the intensity of PA (e.g., moderate and vigorous) than the total volume of habitual PA undertaken as can be determined using pedometers. Whereas, in adults, ambulatory PA comprises a major component of all daily PA and alongside fully mature postural sway may mean the association between PA and sway has higher fidelity and is more stable. Similarly, the association between habitual PA may not relate well to the capacity to balance in quiet stance in children where the number of steps accrued during a given day would likely entail relatively little emphasis on balance skills. Indeed, prior research has reported no differences in postural control between ballet dancers (where precise control of upright posture is a prerequisite) and track and field athletes (Schmit, et al., 2005) and similar postural sway between adult gymnasts and non-athletes (Gautier, Thouvarecq, & Larune, 2008). Although athletic status/experience is qualitatively different to habitual physical activity, taken collectively, the results of the present study and those of Schmit et al (2008) and Gautier et al (2008) suggest that PA status is not associated with the ability to balance in quiet stance.

The present study is not without its limitations. Participants' postural balance was measured during quiet bilateral stance. This might explain the minimal associations between postural sway variables, BMI and PA. Offering a reduced base of support or desensitisation of base of support (e.g., standing on foam) may uncover stronger associations between BMI or PA and sway variables in future studies. Unfortunately, we were unable to complete this additional form of assessment in the current study. PA was assessed by pedometry in the current study which has been shown to be a valid, reliable and objective measure suitable for assessing children's PA (Duncan, et al., 2007). However, pedometers only capture ambulatory PA and future studies may benefit from employing accelerometry to gain a better measure of PA that also allows for determination of time spent in different intensities of PA when examining PA in relation to postural sway variables.

This work provides a better understanding of postural control in children by accounting for BMI and habitual PA when examining differences in sway variables in different visual feedback conditions. These results suggest that postural sway in children is negatively impacted when visual feedback is removed but that neither BMI or PA are associated with postural sway variables.

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Table 1. Pearson's product moment correlations between BMI and physical Activity (average steps/day) and sway parameters in eyes open and eyes closed conditions (* P = 0.01)

	Eyes Open				Eyes Closed			
	anterior/posterior COP Displacement (cm)	Medial/lateral COP Displacement (cm)	Average Sway Velocity ($cm \cdot s^{-1}$)	95% Ellipse (cm^2)	anterior/posterior COP Displacement (cm)	Medial/lateral COP Displacement (cm)	Average Sway Velocity ($cm \cdot s^{-1}$);	95% Ellipse (cm^2)
Average Steps/Day	-0.153	0.16	-0.07	0.01	0.003	0.08	-0.06	0.07
BMI (kg/m^2)	-0.03	-0.1	-0.61*	0.04	0.01	0.06	-0.61*	0.02

Table 2. Mean ± SE of sway parameters in eyes open and eyes closed conditions

Eyes Open								Eyes Closed							
anterior/posterior COP Displacement (cm)		Medial/lateral COP Displacement (cm)		Average Sway Velocity		95% Ellipse		anterior/posterior COP Displacement (cm)		Medial/lateral COP Displacement (cm)		Average Sway Velocity		95% Ellipse	
M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
2.7	.2	2.1	.1	4.8	.2	4.7	.7	3.8	.2	2.9	.2	5.2	.2	8.2	1.1

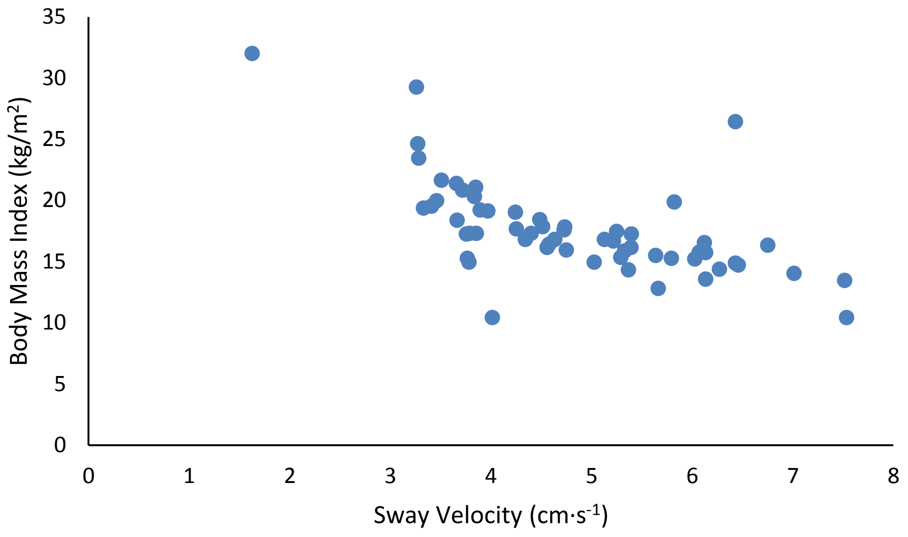

Figure 1. Scatterplot evidencing the relationship between Body Mass Index (kg/m2) and Sway Velocity (cm·s^{-1}) in eyes open conditions.

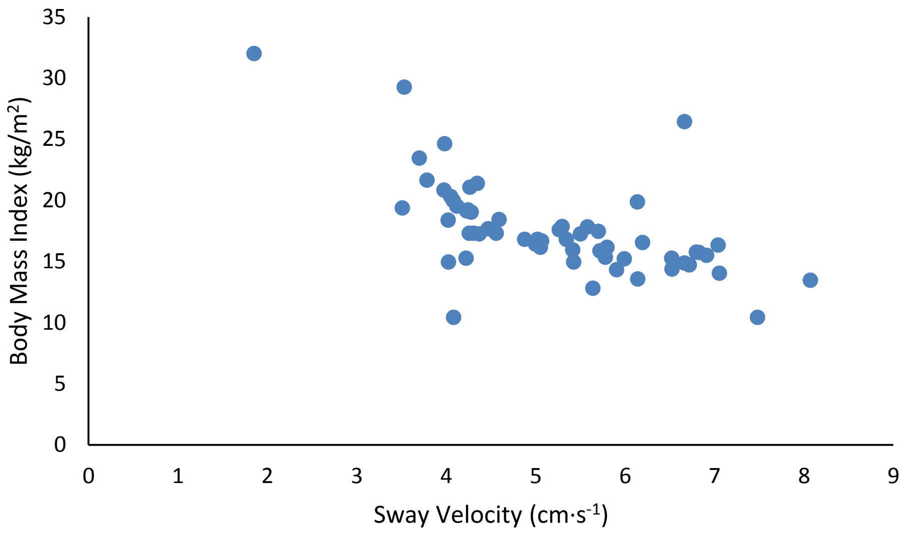

Figure 2. Scatterplot evidencing the relationship between Body Mass Index (kg/m2) and Sway Velocity (cm·s^{-1}) in eyes closed conditions.